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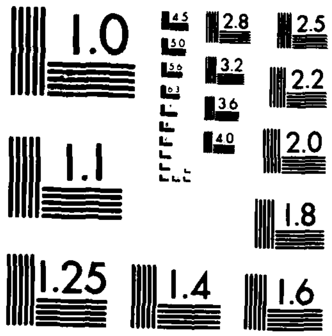
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Department of Structural Engineering Report
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Magnetomechanics Research

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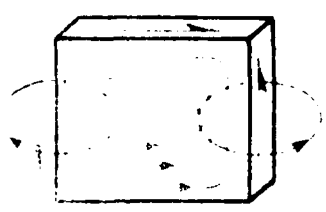

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Technical Report

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Cornell University
Ithaca, New York 14853

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PRE- AND POST-PROCESSING FOR STREAM-FUNCTION EDDY CURRENT CALCULATIONS*

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A stream-function method for the calculation of eddy currents in thin plates has been formulated by finite elements. To make this computational tool more effective, interactive computer graphics techniques are employed to ease the time-consuming tasks of data preparation and result interpretation. These pre- and post-processing capabilities are demonstrated by their application to a study of power dissipation in plates of various shapes.

INTRODUCTION

A stream function or vector potential for the current density vector has been used to develop a finite element code called EDDY2 for calculating induced currents in thin conducting plates for steady-state harmonic external fields [4]. While two-dimensional, the code includes self-field effects for harmonic fields for skin depths on the order of the plate thickness and larger. The input to this Fortran program includes the geometry and properties of the plate, the boundary conditions, and a description of the external magnetic field; this information must all be expressed in terms of the nodes and elements of the computational mesh devised by the analyst. The program produces values of the stream function of the nodes and, at sampling points interior to each element, values of the eddy current, the temperature induced in a half cycle of the current, and the time-averaged magnetic pressure.

Although this program has proven to be computationally effective, as with all finite element programs, a significant amount of effort is consumed by the preparation of error-free input data and the reduction and presentation of the analysis results. To expedite the consideration of a large number of configurations in research or design, interactive graphics techniques can be used. Such computer assistance in the design of a mesh and in the preparation of input data is known as preprocessing, while the manipulation and display of program output is termed postprocessing [1]. Effective interactive pre- and post-processing can decrease the time required to define and perform an analysis by an order of magnitude.

Pre- and post-processing programs especially tailored to EDDY2 have recently been developed as part of research on magnetomechanics at Cornell University. These programs employ vector graphics displays and are controlled by a combination of the terminal keyboard and a digitizing tablet with electronic pen. The preprocessor is menu controlled, that is, a list of possible commands or actions is displayed on the screen, and the analyst activates various commands by pointing to them. Moreover, much of the data input and generation is performed graphically with the stylus, although alphanumeric entry is by keyboard. These two programs are explained and demonstrated in the following through an example problem which is part of a study of power dissipation in plates as a function of plate geometry. The particular configuration chosen for this example is a rectangular plate with opposite semicurcular notches at the center of the long sides.

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PREPROCESSING

The preprocessing program, called PREDDY2, has four main functional branches as shown in the main menu "page" or display, Figure 1. These four branchs include CREATE GEOMETRY, CREATE MESH, ATTRIBUTES, and CREATE LOADS. In addition, one can read a file to resume preprocessing work begun in an earlier session. Finally, the bottom portion of the menu on this and other pages is used for various standard commands, such as HELP (which causes documentation of selected commands to appear on the terminal).

Normally, the first step in preprocessing is to enter the CREATE GEOMETRY page, Figure 2. Here, the basic shape of the plate is defined in terms of a number of subregions which are later used for meshing purposes. The subregion boundaries consist of points, lines, and arcs, each of which may be located either by means of the digitizing pen (P) or by keying in coordinates of control points (K). To aid in the positioning of control points by the pen, a background grid can be specified and displayed; points are automatically positioned on the grid lines if the analyst places his pen down sufficiently close to the grid line. In the example shown in Figure 2, one quarter of the notched plate has been described by several three- and four-sided subregions.

When one, more, or all of the subregions are defined, the CREATE MESH page, Figure 3, is used to fill in each subregion with an appropriate finite element mesh. EDDY2 employs only 6-noted triangular elements, to these are the only option provided in the preprocessor. The meshing techniques described by Haber et al. [3] have been implemented. First the analyst DEFINEs the number of segments along each curve of a subregion outline. This segmentation must follow definite restrictions. For example, each side of a three-sided region must have the same number of segments; however, the spacing of nodal points need not be uniform and is controlled by the analyst. Then the analyst SELECTs a subregion by pointing to its sides one at a time; more than one curve may be concatenated to form a side. Subsequently, when the

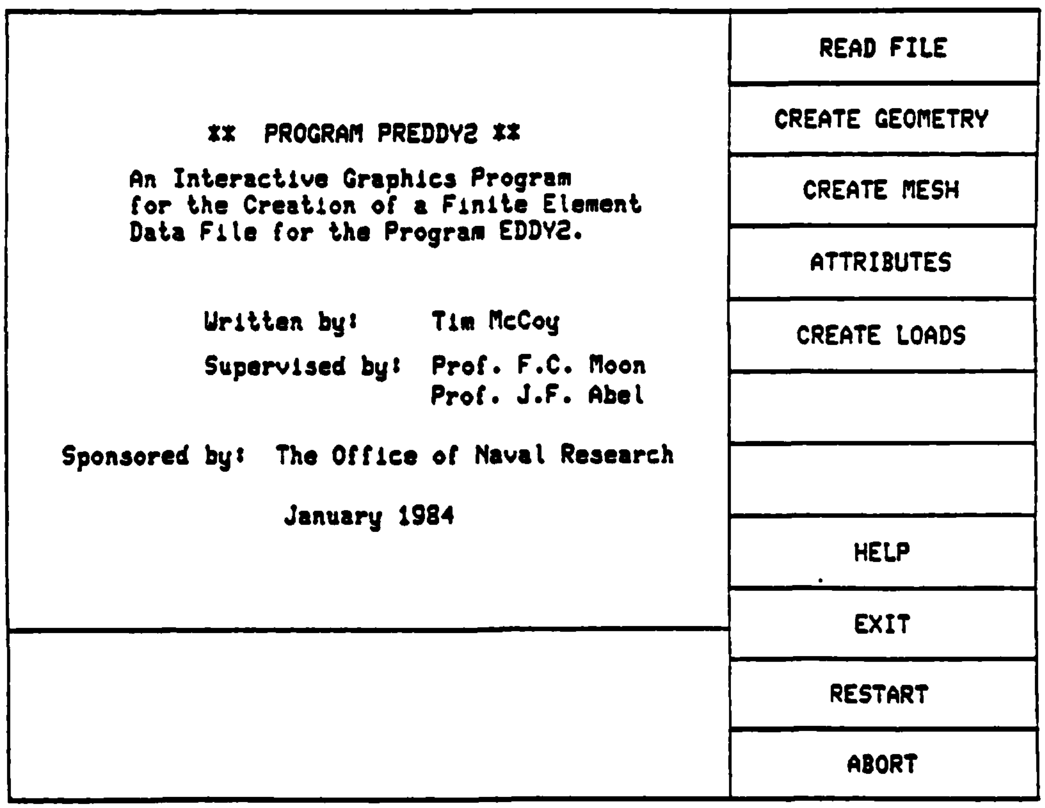

Figure 1
Main Menu Page of Preprocessor

MESH command is chosen, the meshing algorithm appropriate to the number of sides selected is involved. The meshing schemes available include two-sided (lofting), three-sided, and four-sided mappings [3]. Finally, if necessary, the SYMMETRY option may be employed to mirror the created mesh about a selected line. Figure 3 shows the mesh before duplication by symmetry has been accomplished.

The boundary conditions and plate properties are assigned within the ATTRIBUTES page, Figure 4. The boundary conditions are specified or changed either node-by-node or for all nodes on a curve or line. The options available in the preprocessor are "inner" nodes (no conditions applied), "outer edges" (zero value of stream function), "inner edges" (nonzero uniform values of stream function), or "symmetry." The plate properties are specified by associating a thickness and magnetic Reynold's number [4] with elements or subregions (groups of elements). In Figure 4, a Reynold's number of 0.02 and a thickness of 2.0 has been assigned to the entire plate, and the complete outer boundary has been identified.

The final stage of preprocessing is the specification of the applied external magnetic field by means of the CREATE LOADS menu, Figure 5. Although the excitation may arise from dipoles, straight wires, or circular coils, in this case a uniform transverse field is selected. Upon completion of problem definition, one RETURNS to the main menu page, Figure 1, and selects EXIT; at this time, a complete input data set for EDDY2 is created.

POSTPROCESSING

Upon the completion of the finite element analysis with EDDY2, one obtains not only the traditional tabulated output file for printing or listing but also appropriate data files that can be read by the postprocessing program called POSTEDDY2. The output file contains a summary of the problem definition (i.e., all the input data) plus tabulations of the nodal values of the stream function and of the values of the eddy current, temperature increase, and

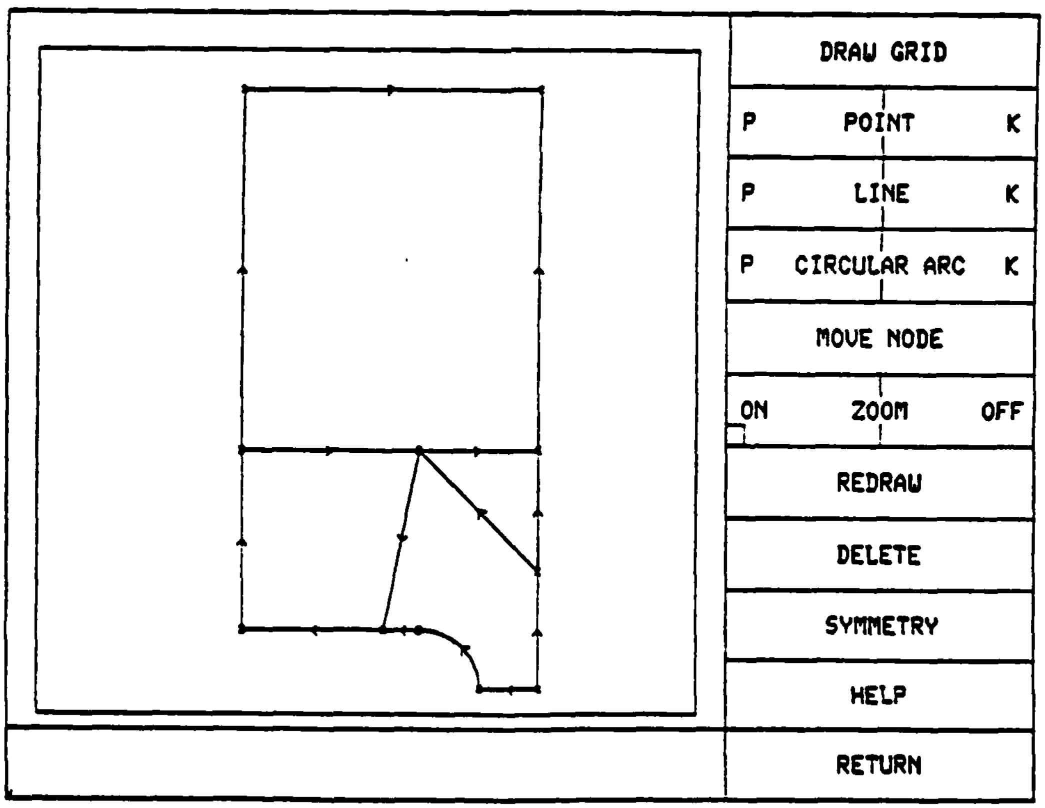

Figure 2
CREATE GEOMETRY Page of Preprocessor

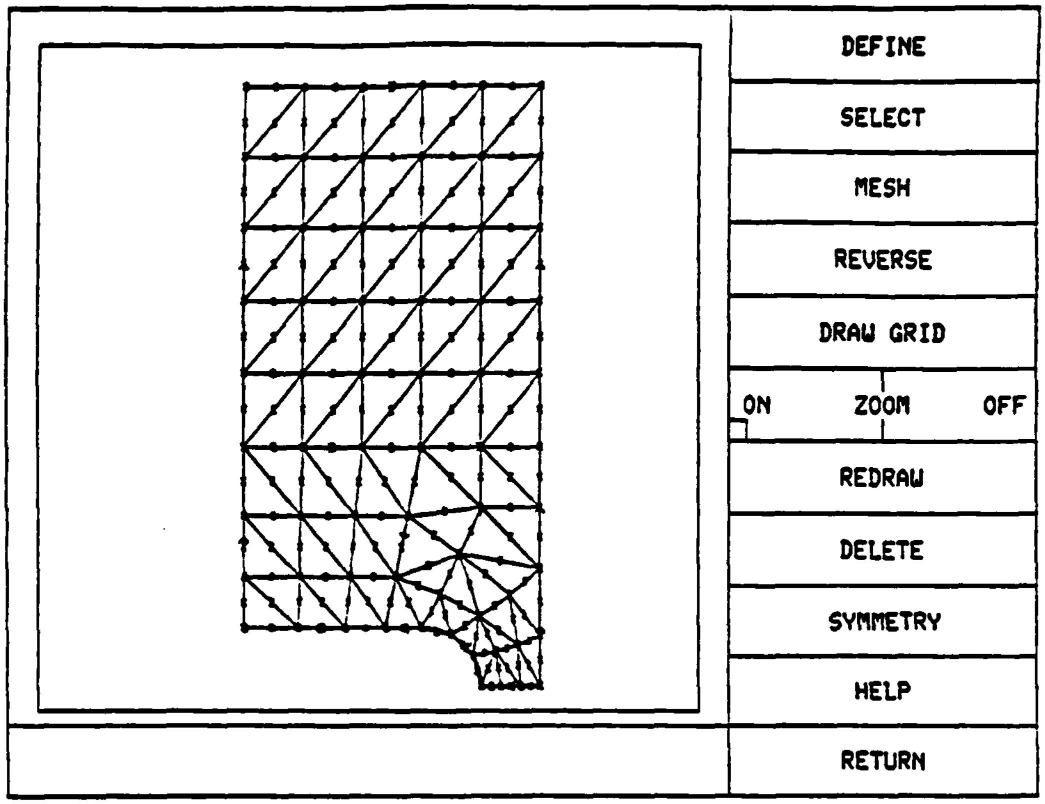

Figure 3
CREATE MESH Page of Preprocessor

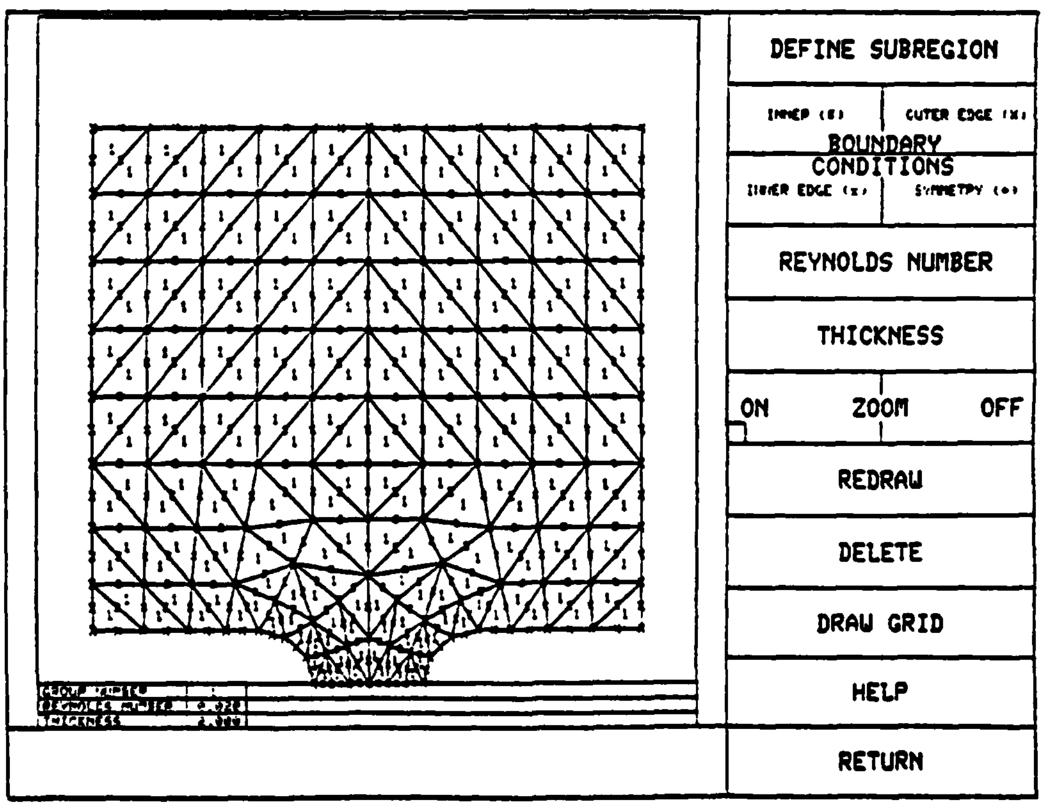

Figure 4
ATTRIBUTES Page of Preprocessor

magnetic pressure at the sampling points. These tabulations are difficult to interpret without some form of graphing, and the purpose of POSTEDDY2 is essentially to produce contour plots of the various spatially varying results rapidly enough for the engineer to modify them as necessary and to select desired hard copies.

The first function performed by POSTEDDY2 is the smoothing of the results available only at the four sampling points within each six-noded triangular element. This is performed by first extrapolating from the four interior points to the six nodes by the least-squares fitting of a plane to the four values. The extrapolated values for each node are then averaged for all elements adjacent to the node to obtain a smoothed distribution. The resulting field is assumed to vary quadratically within each element, that is, according to the interpolation usually associated with six-noded finite elements. The contouring algorithm consists of three phases: (1) the subdivision of the triangular elements into subtriangles, (2) the interpolation of parameter values for the three corner nodes of each subtriangle, and (3) the detection of the intersection of contour lines with the sides of each triangle. Because the path of a contour within each subtriangle is assumed to be straight in this method, the smoothness of the contours is influenced by the degree of subdivision of the parent elements; this is entirely under the control of the analyst, who is asked to specify this factor. For instance, if the analyst selects a subdivision value of 2, each element is divided into four smaller triangles, and each of these is further split into four subtriangles.

In addition to the degree of subdivision to be used by the contouring algorithm, the engineer has a number of other choices. He first must choose the types of parameter to be contoured. The maximum and minimum values of this parameter are shown, and the user is asked to select a contour interval. Moreover, the engineer may choose to label the contour diagrams. An additional option available is the plotting of the original finite element mesh. Figures 6 through 8 show the contour diagrams for the stream function, eddy current, and temperature increases, respectively, of the example problem. Each of these figures is produced in a matter of a few seconds so it is easily possible for one to select acceptable degrees of

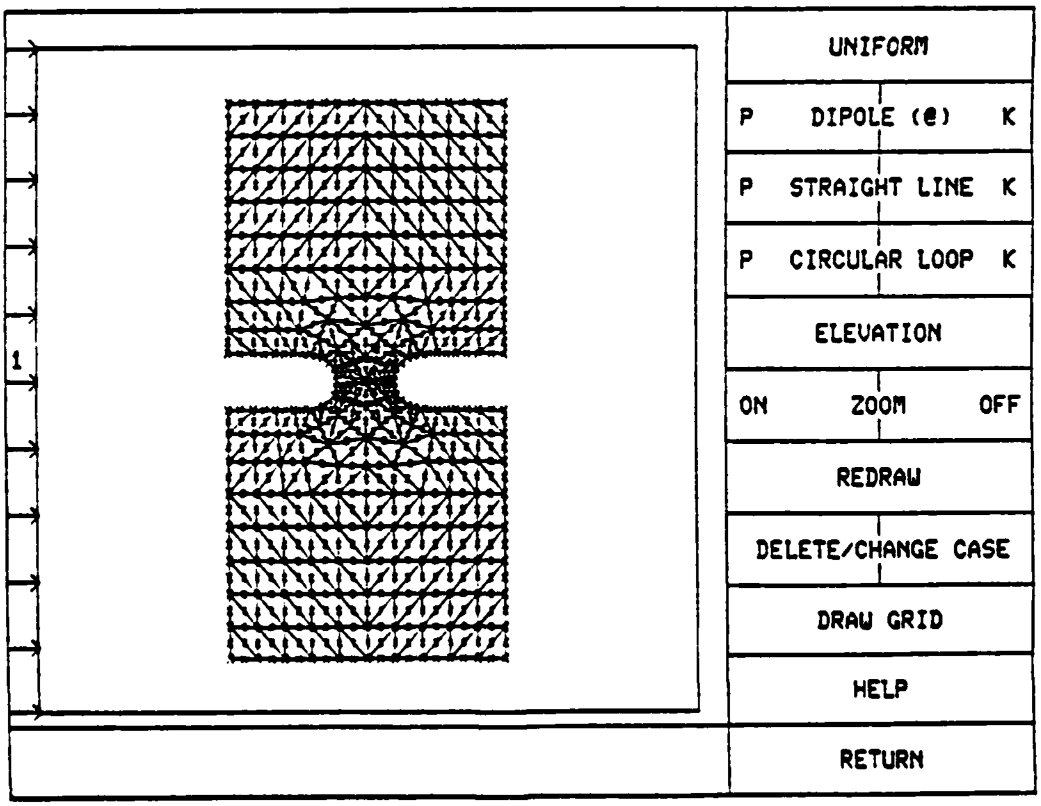

Figure 5
CREATE LOADS Page of Preprocessor

subdivision and contour intervals before one elects to produce a hard copy.

SELECTED RESULTS

One investigation undertaken with EDDY1 and significantly facilitated by PREDDY2 and POSTEDDY2 has been the study of the average power dissipation, i.e., power dissipated per unit area, in plates of various shapes. This study was stimulated by the work of Dresner [2] who showed that, of all possible plate shapes of a given area, the circular plate has the largest power dissipation. He also calculated results for plates of a number of different shapes such as rectangles, triangles, rhobmi, sectors of circular annuli, and L-shaped plates. Initially, all of these shapes were studied, and results were compared to Dresner's both to verify the EDDY2 program and to determine the adequacy of mesh refinements to be used for further finite element analyses of eddy-current power dissipation.

Two of the configurations selected for further study are shown in Figure 9 together with the characteristic dimensions chosen. One of the shapes is the notched-plate form used as an example in this paper, while the second is the shape of a typical transformer plate. (The notch-tip radius is L/20.) The geometric parameters N/L and W/L for the notched and transformer plates, respectively, were varied, and the average power dissipations obtained are summarized in Figure 10. These results are for a harmonically varying uniform transverse field applied to the plates. For the notched plates the average power dissipation decreases as the notches are made deeper, while for the transformer plates it becomes greater as the plates are made less slender.

CONCLUSION

The interactive graphical pre- and post-processing developed for two-dimensional eddy current calculations by the finite element method have significantly enhanced the effectiveness of this technique for plates of arbitrary and complex shapes. Although the preprocessor does not relieve the analyst of the responsibility of proper mesh design, it does ease this task. By extrapolation, it is apparent that similar graphical aids are of even greater utility for three-dimensional computations [1].

ACKNOWLEDGEMENTS

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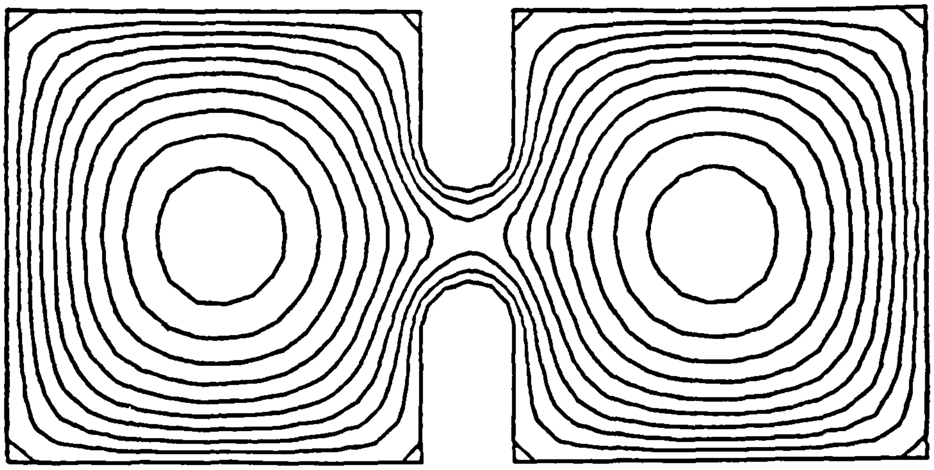

Figure 6
Contours of Stream Function from Postprocessor
(Range 0 to 23.65 by increments of 2.15)

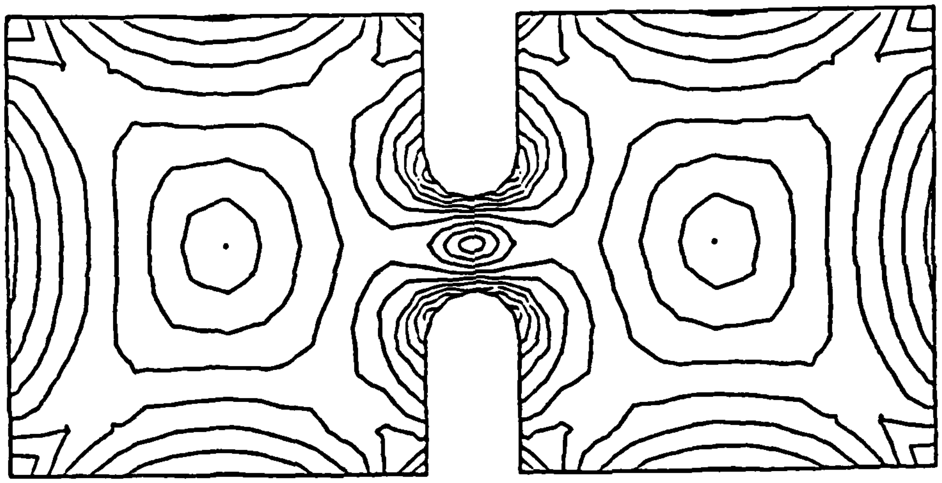

Figure 7
Contours of Eddy Currents from Postprocessor
Range 0 to 2.80 by increments of 0.28)

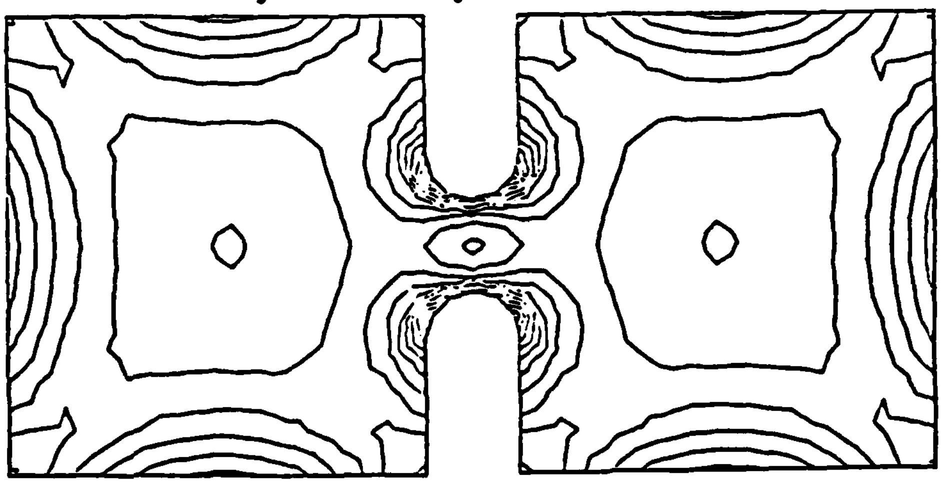

Figure 8
Contours of Temperature Increases from Postprocessor
(Range 0 to 7.50 by increments of 0.75)

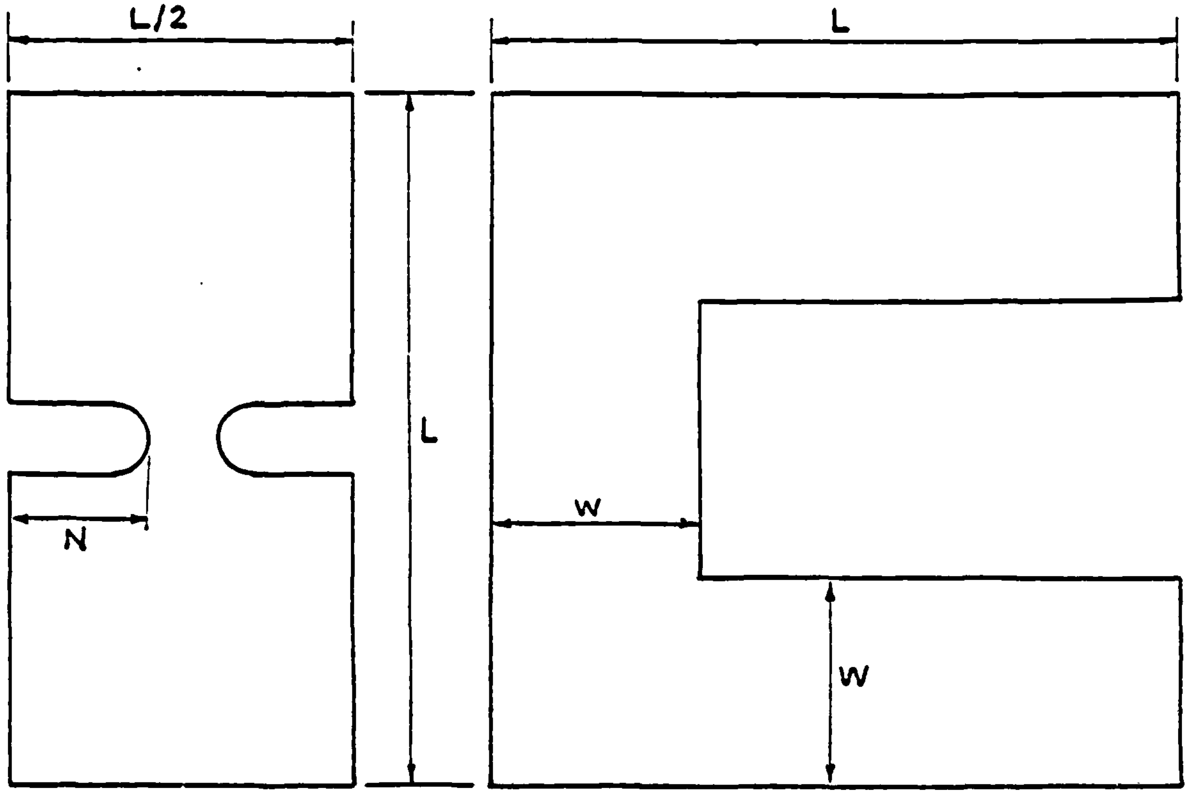

Figure 9
Notched-Plate and Transformer-Plate Configurations Studied

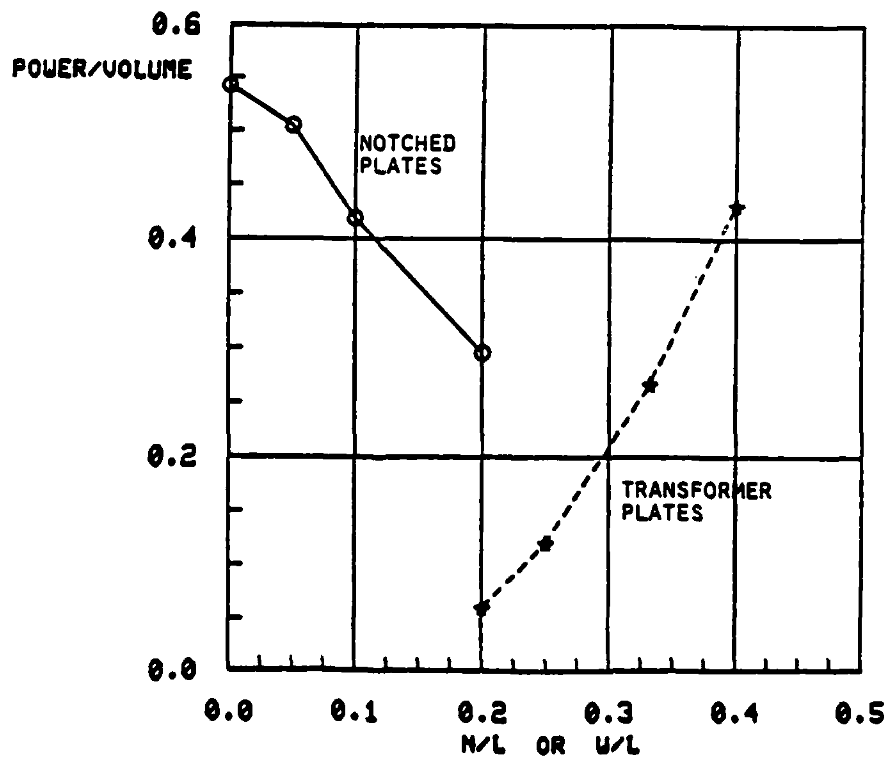

Figure 10
Power/Volume as a Function of Plate Geometry for Notched Plates
and Transformer Plates

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1. K. Y. Yuan, F. C. Moon, and J. F. Abel, "Numerical Solutions for Coupled Magnetomechanics", Department of Structural Engineering Report Number 80-5, February 1980.

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